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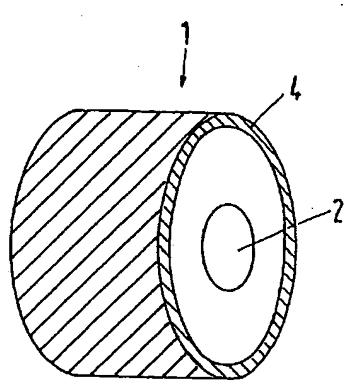
(54) Title: METHOD OF PRODUCING MAGNETIC POLES ON A BASE MEMBER, AND ROTOR OF AN ELECTRICAL MACHINE



(57) Abstract

A method of producing magnetic poles on a base member (1) is disclosed. It is desirable to be able to improve this method. To that end, the permanent magnet material is sprayed onto the base member (1) by a thermal process and is subsequently magnetized.

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Method of producing magnetic poles on a base member, and rotor of an electrical machine.

The invention relates to a method of producing magnetic poles on a base member, and furthermore to a rotor of an electrical machine which has poles that are formed by permanent magnets.

In the following description a rotor of an electrical machine shall serve as an example for explaining the invention. The method for producing magnetic poles may, however, also be applied in the case of other items, for example, in the case of armatures or stators of linear motors and in the case of other items and devices which require permanent magnets.

In electrical machines, the magnetic poles on the rotor are in some cases formed by permanent magnets. Such constructions are well known both for synchronous machines and for d.c. machines. The magnets are then in the form, for example, of arcuate shaped members which are mounted on the rotor. Fixing is effected by means of adhesive or other mechanical connections. Permanent magnets, encapsulated as bars in the rotor, are an alternative thereto. These are then referred to as embedded (buried) magnets. Magnetization of the permanent magnets can be effected before or after mounting. At any rate, a series of operations are required to complete the rotor.

More of a problem, however is the fact that the permanent magnets on the rotor are subjected to relatively high centrifugal forces, which consequently

place great demands on the fixing between the rotor and permanent magnets. This fixing is moreover exposed to the effect of heat, which is inevitably produced during operation of the electrical machine. Many adhesives reduce or lose their retentive force at elevated temperatures. Up until now the permanent magnets have therefore been a weak point of electrical machines.

The invention is based on the problem of improving the production of magnetic poles on a base member.

That problem is solved in a method of the kind mentioned in the introduction in that a permanent magnet material is sprayed onto the base member by a thermal process and is subsequently magnetized.

Thermal spray-application produces on the base member a layer of the permanent magnet material, which is very firmly joined to the base member and additionally has inherently a very stable cohesive strength. A high mechanical strength is achieved as a result. The base member and the magnetic poles hold together in a very secure manner. The base member is therefore well able to withstand stress. Because the permanent magnet layer is applied by spraying, the thickness of this layer can be controlled very easily. The thickness of the layer determines, inter alia, also the strength of the permanent magnets produced subsequently.

The permanent magnet material is preferably sprayed on in the form of a powder. In the case of thermal spraying, the individual powder grains are then on the one hand bonded to the surface of the base member and on the other hand also to each other. This produces a very stable bond of the powder on the surface of the base member. Moreover, such a powder is easy to

handle, so that it is possible to build up a layer with relatively little effort.

Advantageously, the powder has a grain size in the range from 0.1 to 200 μm, especially from 1 to 10 μm. With such a grain size a very stable and cohesive structure of the layer of the permanent magnet material can be observed.

NdFeB is preferably used as the permanent magnet material. This material has very good magnetic properties, for example, a large energy density. The use of NdFeB as rotor magnet material is known <u>per se</u>. Until now, however, it has been used in shell or bar form, these shaped bodies being produced by sintering, hot-pressing, or by polymer compounds. It has now been discovered that this material is excellently suited to being sprayed on in powder form if a thermal process is used for that purpose, that is, if heat is supplied at the same time as spraying takes place.

The base member is advantageously subjected to a heat treatment after the permanent magnet material has been sprayed on. During the thermal spraying, a structural change of the permanent magnet material may in fact take place. This can be critical, for example, when the starting powder is crystalline, but after being sprayed on has an amorphous structure. If, for example, NdFeB is used, the constituents Fe and Nd in the starting powder have an intermetallic bond with one another which is able to disintegrate after the thermal spraying. This structural change may possibly render the material no longer directly magnetizable. The heat treatment that can be carried out, for example, in the case of NdFeB, in a temperature range between 800° and 900°, to a great extent restores the crystalline

structure of the sprayed-on layer. This renders subsequent magnetization of the base member possible.

The heat treatment is preferably effected in a non-oxidizing atmosphere. In this manner the sprayed-on layer is prevented from oxidizing during the heat treatment.

Advantageously, the thermal process is in the form of high-speed spraying or plasma-spraying. With plasma spraying, very high temperatures are reached; the powder need be subjected to these temperatures only very briefly, however. The grains of the powder then fuse at their surface. This produces a very good cohesive strength of the layer in itself and with the base member, without the structure of the permanent magnet material used being destroyed any more than necessary. Plasma spraying of such materials is known from EP 0 339 767 A2. That publication also discloses how such a method is carried out.

It is especially advantageous for the plasma spraying to be carried out at a temperature in the range from 5,000° to 15,000°C. Good results were observed at these temperatures.

Advantageously, the surface of the base member is roughened prior to the spraying operation. This increases the strength of the bond between the sprayed-on permanent magnet material and the base member. Once the first layer of permanent magnet material has been applied to the base member, the surface of the base member is in any case rough, so that subsequent layers are likewise firmly held.

In a very especially preferred construction, provision is made for the surface of the permanent magnet material to be made smooth after the spraying operation, in particular by grinding. After the spraying operation, the surface of the base member, or more accurately, the surface of the permanent magnet material, has a rough surface, which has "valleys" and "peaks". There is here probably a danger that during magnetization the "molecular magnets" become oriented in such a way that their actions virtually cancel each other out. In that case only very weak magnetism occurs. If, on the other hand, the surface is made smooth, all "molecular magnets" are oriented in the direction of the magnetic field applied and persist in that orientation so that the desired strong magnetization is produced. (The term "molecular magnets" is here used for reasons of clarity).

Preferably, the base member is made of metal, in particular soft iron. Besides the well-known good magnetic properties of such a material, the use of a metal, especially soft iron, has the advantage that the sprayed-on layer of permanent magnet material holds firmly thereto, because by virtue of the elevated temperature it is virtually welded to the base member.

The base member is advantageously in the form of a rotor of an electrical machine. This is one of the most important areas of application of the manufacturing method.

The rotor is advantageously turned during the spraying operation. On being sprayed, the rotor is therefore subjected to a uniformly rotary movement. Even when the permanent magnet material is supplied from only one position, it is possible in this manner to form a

relatively uniform and homogeneous layer, in which the permanent magnets are later produced. This layer is formed from many partial layers which are, as it were, wrapped around the rotor. The thickness of the layer can be adjusted relatively easily by changing the number of revolutions of the rotor and/or the rotational speed of the rotor. In a nutshell, the spraying time is changed. After spraying, a layer thickness of the order of magnitude of 1 mm is typical.

The permanent magnet material is preferably provided with a protective layer after being sprayed on. Such a protective layer protects the permanent magnet material against oxidation, for example.

The problem is solved in a rotor of an electrical machine in that the permanent magnets are formed in a sprayed-on layer of permanent magnet material. Such a layer holds, as explained above in connection with the manufacturing process, very firmly to the rotor and also forms in itself a relatively strong and thus resistant cohesive bond so that the rotor is able to withstand stress relatively well.

The invention is described hereinafter with reference to a preferred embodiment in conjunction with the drawings, in which:

Fig. 1 shows a base member for a rotor,
Fig. 2 shows the rotor, which is provided with a layer of permanent magnet material,
Fig. 3 shows the rotor in plan view,
Fig. 4 shows the rotor in longitudinal section,
Fig. 5 shows an electron micrograph of NdFeB in a powder state and
Fig. 6 shows an electron micrograph of NdFeB after it has been sprayed on.

Fig. 1 shows a rotor 1 of an electrical machine in its unfinished state. Either the rotor 1 is in the form of a solid body of soft iron or it consists of laminations stacked one on top of the other, between which insulators are provided in order to avoid the formation of eddy currents. The construction of the rotor 1 as a base member is not significant for the following description, however. The rotor 1 has a central bore 2 which later serves to receive a rotor shaft.

The rotor 1 has a circumferential surface 3 which has been roughened, for example, by sand-blasting or grinding. A layer 4 of a permanent magnet material, in this case NdFeB, is applied to the circumferential surface 3, as can be seen in Fig. 2. This permanent magnet material is preferred because of its good magnetic properties, in particular its great energy density. Other materials also can be used, however, for example, samarium cobalt, ferrites or rare earths.

The layer 4 can be provided with a further protective layer 5 in order to avoid oxidation.

The rotor is made as follows. NdFeB powder, which is shown on an enlarged scale by an electron micrograph in Fig. 5, is applied to the surface 3 of the rotor 1 by plasma spraying. Plasma spraying is known per se and belongs to the category of thermal spraying in which the powder can be applied at a high temperature to the surface 3 of the rotor 1. To carry out the plasma spraying, the NdFeB powder is heated in a plasma spraying apparatus to a plasma at a temperature in the typical range from 5,000° to 15,000°C, whereupon the surface of the powder material fuses. The powder is then sprayed onto the rotor 1 which rotates steadily during the spraying so that the layer is sprayed on

uniformly. Fig. 2 shows the rotor 1 after spraying. The NdFeB layer 4 is shown hatched.

The thickness of the layer 4 can be changed in a simple manner by prolonging or shortening the spraying time. For example, the rotor 1 can be turned more quickly or more slowly or a greater number of revolutions can be performed.

The typical thickness of the layer 4 after spraying is about 1 mm. Alternatively, it can vary in a range from a few μm to several mm.

It has been found that through plasma spraying, with the same magnetic output of the rotor less NdFeB material needs to be applied than would be the case with preformed parts. This is possibly connected with the fact that the density of the permanent magnet material can now be controlled very much more precisely. It is probable too that air gaps between the rotor and the layer are avoided.

The NdFeB powder can have a grain size in the range from 0.1 μm to 200 μm. Preferably, however, a grain size in the range from 1 μm to 10 μm is used.

Because of the high temperature that is used in plasma spraying, the individual particles or grains of the powder are welded during spraying partly to the surface 3 of the rotor and partly to other particles. This welding produces a very good cohesive strength of the powder in itself and of the powder with the surface 3 of the rotor. As a consequence, the rotor 1 can also be exposed to relatively high speeds of rotation, the layer 4 being subjected to correspondingly large centrifugal forces.

During plasma spraying of the NdFeB material, however, there is a structural change. The starting material is crystalline. After the spraying, however, an amorphous structure can be observed. In the starting powder the constituents Fe and Nd have an intermetallic bond with one another which in many cases disintegrates after the plasma spraying. This is recognizable in Fig. 6, for example. The result of this change from a crystalline structure to an amorphous structure is that the material can no longer be directly magnetized. In order to recreate the crystalline structure of the sprayed-on material, the rotor 1 is exposed to a heat treatment with the sprayed-on material at a temperature around 800° to 900°C, for example 850°C. By that means the crystalline structure of the starting material is recreated. Subsequent magnetization of the rotor is then possible.

After the plasma spraying operation, the surface of the layer 4 is relatively rough. When such a surface is magnetized, in many cases the magnetism produced is only weak. This is attributable to the fact that the "molecular magnets" are able to orientate themselves in such a way that their actions virtually cancel each other out. To avoid this effect, the surface of the layer 4 is made smooth by grinding off a thin layer of the order of magnitude of about 0.1 mm, or by polishing.

Both the heating and the smoothing operations are effected preferably in an atmosphere that prevents oxidation. Otherwise, in particular when using NdFeB, the risk of oxide formation is relatively high.

The protective layer 5 can be applied after the smoothing operation.

The rotor is then ready for magnetization and can be provided with the desired number of poles. For example, magnetization of the rotor can be effected with a magnetic field strength of 3200 kA/m. Alternatively, the magnetic field strength can be varied according to need.

The protective layer 5 can, of course, also be applied after magnetization.

Several advantages can be achieved with the described procedure. First of all, a relatively simple manufacturing process with few work steps is achieved. Secondly, a more robust rotor is produced, since fewer parts are present in the rotor and the magnets are very reliably mechanically fixed to the base member of the rotor. Thirdly, by varying the spraying time and the magnetization current, different rotors can be matched to the required specifications relatively quickly, that is, individual rotors can be tailored to requirements. Finally, compared with conventional manufacturing processes, a saving on the amount of permanent magnet material can be achieved.

As stated at the outset, the method is not restricted to the manufacture of rotors for electrical machines. It is possible also, of course, to produce armatures and stators of linear motors. Sensors having magnetic poles tailored to requirements can be made. Valves or other actuating elements with permanent magnets can also be manufactured in this manner.

Patent Claims

1. A method of producing magnetic poles on a base member, characterized in that a permanent magnet material is sprayed onto the base member by a thermal process and is subsequently magnetized.

2. A method according to claim 1, characterized in that the permanent magnet material is sprayed on in the form of a powder.

3. A method according to claim 2, characterized in that the powder has a grain size in the range from 0.1 to 200 μm, especially from 1 to 10 μm.

4. A method according to one of claims 1 to 3, characterized in that NdFeB is used as permanent magnet material.

5. A method according to one of claims 1 to 4, characterized in that the base member is subjected to a heat treatment after the permanent magnet material has been sprayed on.

6. A method according to claim 5, characterized in that the heat treatment is effected in a non-oxidizing atmosphere.

7. A method according to one of claims 1 to 6, characterized in that the thermal process is in the form of high-speed spraying or plasma-spraying.

8. A method according to claim 7, characterized in that the plasma spraying is carried out at a temperature in the range from 5,000° to 15,000°C.

9. A method according to one of claims 1 to 8, characterized in that the surface of the base member is roughened prior to the spraying operation.

10. A method according to one of claims 1 to 9, characterized in that the surface of the permanent magnet material is made smooth after the spraying operation, in particular by grinding.

11. A method according to one of claims 1 to 10, characterized in that the base member is made of metal, in particular soft iron.

12. A method according to one of claims 1 to 11, characterized in that the base member is in the form of a rotor of an electrical machine.

13. A method according to claim 12, characterized in that the rotor is turned during the spraying.

14. A method according to one of claims 1 to 13, characterized in that after being sprayed on the permanent magnet material is provided with a protective layer.

15. Rotor of an electrical machine, which rotor has poles that are formed by permanent magnets, characterized in that the permanent magnets are formed in a sprayed-on layer (4) of permanent magnet material.

Fig.1

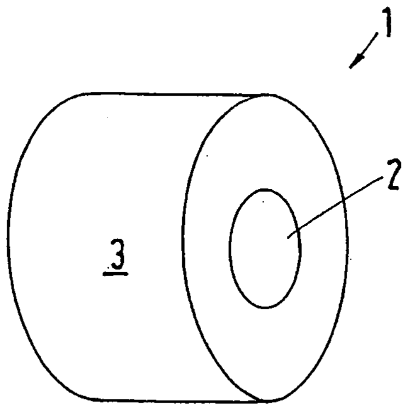


Fig.2

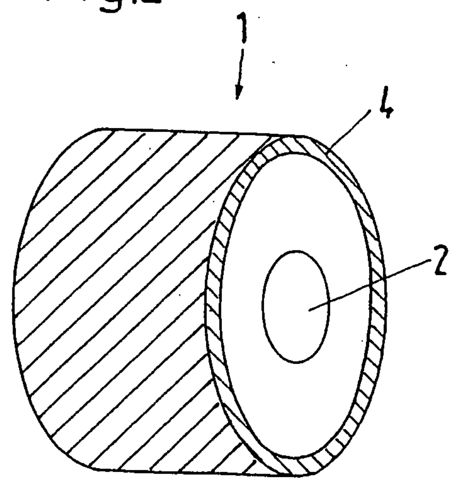


Fig.3

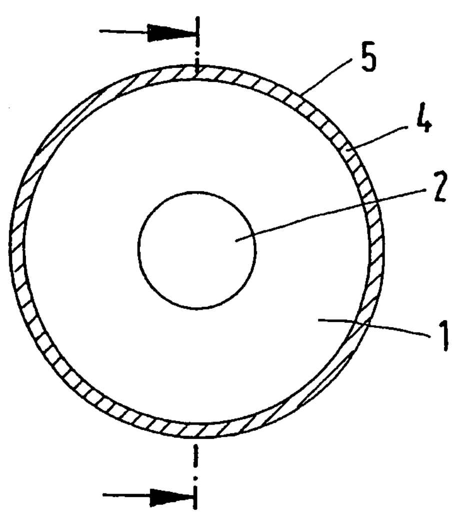
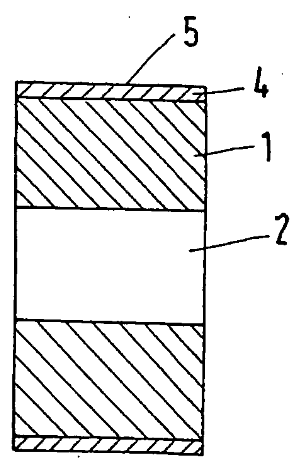


Fig.4



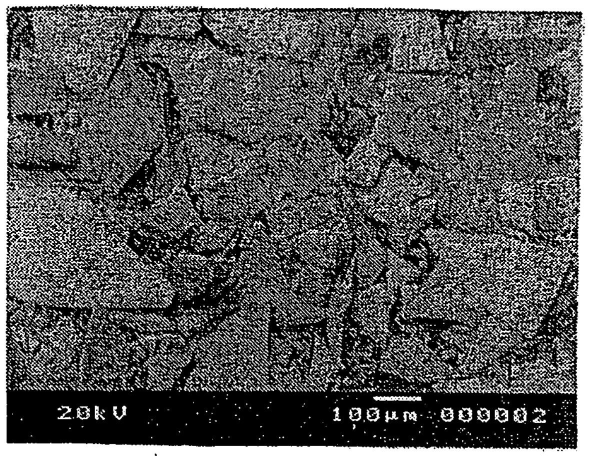


Fig. 5

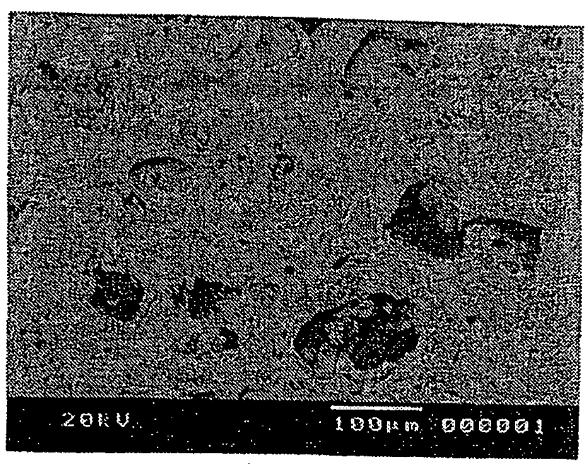


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 96/00358

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01F 1/09, H02K 1/27, C23C 4/04
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: C23C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, CLAIMS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Dialog Information Services, File 347, Japio database, accession no. 03803859, KOMATSU LTD: "Alternator", JP,A, 04-168959, 9206-17	1,12,15
Y		4,5,6,7
A		2,3,8-11,13, 14
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X	DE 4230676 A1 (TRIDELTA AG), 17 March 1994 (17.03.94)	1,2,7
A		3-6,8-15
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
11 December 1996	13 -12- 1996
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International application No.
PCT/DK 96/00358

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5225004 A (ROBERT C. O'HANDLEY ET AL), 6 July 1993 (06.07.93), column 8, line 6 - column 9, line 55; column 9, line 56 - column 10, line 4; column 10, line 37 - line 46	4,5,6,7
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International application No.
PCT/DK 96/00358

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT
Information on patent family members

28/10/96

International application No.
PCT/DK 96/00358

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US-A- 5225004	06/07/93	NONE	
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